Art. XXXV.—*A Contribution to the Physiography of the Yarra River and Dandenong Creek Basins, Victoria.*

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(With Plates LXXXVI.–XC.)

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Introduction.

In this paper an attempt is made to throw some light upon the history of the Yarra River and Dandenong Creek Basins since the last great uplift of the land. The more recent minor changes of the Yarra near its mouth have been described by several writers, and upon these aspects I do not propose to touch. This paper is concerned mainly with the Yarra Valley upstream from Heidelberg, and with the basin of the Dandenong Creek generally. As will be noticed in the sequel, the two basins are in places intimately associated with one another, and thus they may be conveniently dealt with together.

Previous Literature.

Apart from Professor Gregory's work, which will be presently referred to, little has been published on the Yarra and Dandenong Creek Basins. Such literature as exists, and which bears on the subjects in hand, will be mentioned when dealing with the origin of the various land forms.

In 1903 Professor Gregory published his suggestive and stimulating work on the Geography of Victoria (1). In passing I would like to express my deep indebtedness to this book, and to point out that it is practically the pioneer work in Victoria in the application of the principles of modern physiography, of which at the present time Prof. W. M. Davis of America is perhaps the most distinguished exponent.

In this work Professor Gregory (pp. 106-113) discusses the history of the Yarra Basin, and suggests that most of the principal northern tributaries of the Yarra were originally continuous with the principal streams now flowing northerly to the Goulburn River, but formerly having a southerly flow; and also that a stream formed by the junction of some of these older larger streams (the Acheron-Watts and the Yea-Steel's Creek) originally passed over a gap at Beenak, and entered Western Port Bay through the Kooweerup Swamp. This of course was when the general surface of the Yarra Basin was at a greater elevation than it is at present. Subsequently the Yarra and Goulburn Rivers worked their way eastward and captured the various streams, dividing them into two portions in some places, and into three in the case of the river which he thought formerly passed over the Beenak Gap, and of course reversing the flow of some of the captured parts. The Yarra, he states, cut its way along an eastern and western valley, guided by the earth movements that succeeded the eruptions of Dandenong and the Black Spur. These eruptions Professor Gregory elsewhere (2, pp. 212 and 214) states, were probably post-Palaeozoic, and certainly earlier than the Upper Cainozoic, and might belong to any part of the Mesozoic or Lower Cainozoic.

The present paper does not discuss the questions here raised by Prof. Gregory, but confines itself mainly to the history of the Yarra and Dandenong Creek since the last great uplift of the land, which, in the writer's opinion, occurred after the formation of the peneplain, which is subsequently referred to as the Nillumbik Peneplain.

Prof. Gregory (1, p. 84) also refers to the Yarra Plateau as the third southern spur of the peneplain running southward from the Primitive Mountain Chain. This peneplain, he states, ran from the Strathbogie Ranges across the present main divide between Mt. Disappointment and Mt. Arnold, forming the old platform under the Dandenongs. He further remarks (p. 85) that most of the Yarra Plateau may be regarded as a shelf on the eastern border of the Melbourne Basin, of which the eastern boundary may then be drawn along the ridge through Queenstown, Christmas Hills and Mooroolbark.

East of this line is the basin of the Middle Yarra, Kooweerup Swamp and Western Port, which were probably once part of a connected basin.

In the same work (pp. 106-107) Prof. Gregory points out that the Yarra does not cross from its middle basin to its lower basin by what appears to be the natural course—viz., through the gap at Mooroolbark used by the railway, but after meandering through the Yarra Flats the river suddenly turns off into the hilly country known as the Christmas Hills. It flows in a deep gorge through them till it reaches the plains again near its junction with the Plenty River. Its course he maintains is therefore clearly antecedent to the present topography of the country; but its narrow gorge and rocky cataract broken course show that it has here the characters of a young as well as an antecedent river, and is, in fact, a revived river.

The possible peneplain of which the tops of Mt. Macedon and the Dandenong Ranges are the remnants, as suggested by Prof. Skeats (3, p. 188), will not be discussed in this paper.

General Description.

The principal physical features of the areas in question are fairly well known, so that a brief description will be sufficient for the purposes of this paper.

Treating the Yarra first, this river rises near Mt. Baw Baw, and thence passes westward, developing into a fairly open, matured valley, with well-developed tributaries, until it reaches Warburton. Here, as noted by Mr. F. G. A. Barnard (4, p. 245), it is confined to a deep and somewhat narrow gorge, after passing which its valley gradually widens until it turns to the north near Killara, and meanders through broad alluvial flats as far as Healesville, where it swings away again to the westward through similar flats as far as Yarra Glen. It then turns to the south-west, still bordered by flats, but now principally on the left bank only. The right bank rises steeply to a considerable height above the river, and these features are maintained, with the exception noticed below, until Brushy Creek (a southern tributary) is met.

Here the river plunges into a deep narrow gorge: and the stream passes from the slow meanderings indicative of old age to the swift-flowing, rocky-bedded river characteristic of youth. This gorge continues as far as Templestowe, from where the country becomes more open and the river more staid, until at Heidelberg it has a wide-bottomed valley, and the river meanders through its flood-plain.

At Fairfield the river again becomes youthful in appearance, due to the partial infilling of the old valley by basalt. It maintains its narrow valley for some distance; but the valley gradually widens as it approaches Melbourne, becoming once again the mature or old river, which feature it retains until it meets the sea at Hobson's Bay.

The character of the valley at Heidelberg has been described by Dr. T. S. Hall (5, p. 42) and the writer (6, pp. 165 and 166).

The tributaries of the Yarra do not present many diversified forms. Those entering the stream on its right bank comprise streams running mainly through silurian country, such as the Plenty, the Diamond Creek, Watson's Creek, Steel's Creek and others near Yarra Glen. They also include the Watts River, the Badger Creek, the Don and the Dee Rivers, and the small streams near Warburton, all of which belong to dacite country. Farther east there are the O'Shannassy and other rivers, which are silurian.

These tributaries are, with the exception of the small streams at Warburton, deeply trenched, and have, generally speaking, rather narrow valleys. They enter the Yarra with accordant junctions, are well graded, and their development has clearly been determined by the stage of growth of the Yarra itself. In other words, they are normal tributaries.

The tributaries at Warburton are very short, with steep grades and very narrow valleys. Their waters are very swift-flowing, and they, with similar streams on the opposite bank at the same locality, constitute a group of mountain torrents. Their rocks are dacite on the northern, and mainly granodiorite on the southern side.

The affluents entering the Yarra on the left bank are, as a rule, considerably shorter than those entering on the right bank. They comprise Gardiner's and the Koonung Koonung

Creeks, whose valleys are broad open ones, due to the comparatively slight elevation of the country above sea-level, and the mature state of the Yarra where these streams junction. Farther east, the Mullum-Mullum, Anderson's, and Narrmeian Creeks possess narrow, deep valleys, consistent with the Yarra itself at their various points of entrance. The five tributaries just mentioned all have accordant junctions, and are all essentially silurian streams.

The next valley to the east, that of the Brushy Creek, offers a striking contrast to its immediate neighbours, the Narrmeian, Anderson's and Mullum Mullum Creeks. The Brushy Creek valley is a broad, open, flat-bottomed one, with a sluggish stream meandering through its own alluvium, while further east the streams running in a northerly direction towards the Yarra, such as the Olinda Creek and other small watercourses in the parish of Yering, do not reach the Yarra, but lose themselves in the broad, marshy flats bordering the Upper Yarra. The valleys of these streams before entering the flats are bounded by low hills with gently sloping sides.

Beyond the flats again to the east, another nest of closely related streams occurs, including the Woori Yallock Creek, Hoddle's Creek, and the Little Yarra. These are fairly well developed, chiefly in silurian country, and possess the normal characteristics already noted of other similar streams.

At Warburton, as above remarked, mountain torrents exist on both sides of the river.

Farther to the east again, the southern tributaries appear to be generally similar to those entering from the northern side, and are chiefly in silurian country.

The basin of the Dandenong Creek offers in several respects a marked contrast to that of the Yarra. The latter is much larger than the former, which is generally at a low elevation, and is fed by ground of little height, with the exception of some drainage from the Dandenong Mountains. The result is that the main stream—the Dandenong Creek—is very small, and its tributaries, with the exception of the Blind and Corhanwarrabul Creeks, are quite insignificant. A further result is that the valleys are generally wide, shallow and tending to flat bottoms, with alluvial flats. These characteristics are

especially noticable towards the mouth of the Dandenong Creek (where they would be expected), and, where unlooked for, at the head waters of the stream, and its principal tributaries.

The main geological formations may be seen from the map, showing the Yarra and portion of the Goulburn Basins. The main divisions are the silurian sedimentary rocks, the dacite and granodiorite, and the tertiary sands and gravels. The silurian occupies most of the peneplain through which the Yarra runs, as well as forming part of the divides. The granodiorite and dacite form the highest lands of the area, rising to about 4000 feet at Mount Donnabuang, near Warburton. They are found about the divides.

The tertiary sands and gravels forming the coastal plain to the east and south-east of Melbourne, are a thin cap on the silurian rocks, and occur in the southern part of the country now dealt with. They have in places been much deunded.

The Yarra Plateau.

Prof. Gregory's description of the Yarra Plateau has already been quoted. It is proposed to extend the boundaries of this plateau, so as to include country that naturally falls within its area, as well as the coastal plain to the east and south-east of Melbourne. The latter is included for convenience of reference.

The plateau is bounded on the north by the Main Divide, or by some of the spurs of the latter; and Mount Disappointment may be regarded as the western extremity of its northern boundary.

The rise from the plateau at its northern boundary is sharp. This is noticeable at Mount Disappointment, and particularly so at Bear's Sugar Loaf, a high, southerly-projecting spur from the Divide. This spur at its southern end is sharply and steeply truncated, which may be due to denudation during the formation of the peneplain, of which the Yarra Plateau forms a part.

In contrast are the spurs from the Main Divide about Yarra Glen and Healesville. They are long and sloping, and continue

so down into the valley of the Yarra. These spurs indicate that this part of the country has escaped the planation which formed the peneplain, and that such country apparently belongs to an earlier cycle of erosion than the plateau.

Belonging also apparently to this earlier cycle of erosion is the Yarra valley, east of Warburton. This area and the country mentioned in the last paragraph, have not been sufficiently examined to state whether any evidence exists in support of this earlier cycle, such as old valleys trenched by younger ones.

From the Main Divide to the Yarra, the plateau is bounded on the east by the higher country at Steel's Creek and farther east. The boundary then follows the Yarra to Brushy Creek, thence along the western side of the latter to Burt's Hill, thence south-westerly through the Springvale district to the sea. Its western boundary may be regarded as a line drawn from Mount Disappointment southward to Port Phillip Bay.

Another part of the plateau is probably most of the Woori Yallock and Hoddle's Creeks Basins. This part is separated from the main area by the depression of the middle Yarra country. Its exact relations with the main part of the plateau have not yet been determined.

The Croydon Senkungsfeld.

The Yarra Plateau is flanked in parts by a belt of low country, characterised by wide alluvial flats, low ridges and broad, open valleys, of which those at Yarra Glen and Bayswater may be taken as types. The tops of the ridges indicate that this low belt of country had originally a level surface, and is really a dissected plain.

The difference of elevation between the Yarra Plateau and this lower country I regard as due to unequal uplift, the less raised portion being a true Senkungsfeld, which can conveniently be referred to as the Croydon Senkungsfeld. Croydon is situated on the boundary between the Yarra and Dandenong Creek Basins, and as the Senkungsfeld belongs to both, the name of this township has been adopted for this depressed belt of country.

The Senkungsfeld is bounded on the west by a line running north-easterly from about Springvale to the Dandenong Creek (just west of the Bayswater railway station). Crossing the creek it continues in the same direction as far as Burt's Hill. It then runs a little to the west of north to the Yarra at the mouth of the Brushy Creek, then north-easterly to Yarra Glen. From here the boundaries have not been definitely traced, but probably it trends eastward (a little to the north of the Yarra) to Healesville, thence southward close to the great dacite masses of Mounts Riddell and Toole-be-wong to the east of Killara, thence across the valley of the Yarra at the latter place to the Warramate Hills, thence northward along their eastern edge, thence westward to Lilydale, and southerly along the western edge of the Dandenong Ranges and adjacent hills to Dandenong.

Thus this depressed area consists of a long north and south valley running through Croydon to Dandenong, the low country about Yarra Glen, and the narrow valley between Mount Toole-be-wong and the Warramate Hills. Mr. Thiele in his suggestive and interesting little paper (7, p. 103) has noted the depression of the Dandenong Creek area; but suggested no reason for its existence.

The depth of the original surface of the Croydon Senkungsfeld below the general level of the Yarra Plateau is at Croydon about 140 feet (by aneroid), and at the gorges subsequently described as the Yering and Warrandyte Gorges, about 200 feet by the same instrument. At the "Kopje" it is only about 85 feet. Elsewhere the heights have not been determined.

The Lilydale basalt, although higher than most of the depressed area, cannot be separated from the latter. Its greater height is due, in the writer's opinion, to its greater resistance to erosion than the softer neighbouring rocks. The relations of the higher country chiefly occupied by the pyroclastic rocks of Evelyn and surrounding country (which are regarded as related to the dacites), to the Senkungsfeld and the Yarra Plateau, have not yet been determined.

So far as its boundaries have been definitely traced, the Senkungsfeld is mainly due to faulting; it is therefore a fault-block.

For reasons that will be subsequently stated, the Senkungsfeld is regarded as only relatively and not absolutely depressed. The whole country was uplifted, but certain portions received greater elevation than others.

In stating the boundaries of the Croydon Senkungsfeld, no reference was made to its possible extension south of Dandenong, as my personal observations in connection with this paper have not extended beyond this point.

From the known contour of the country, however, to the south of Dandenong, and from the geological map accompanying Selwyn's report of 1856 (8), the Senkungsfeld appears to clearly extend in the same direction (south-westerly) through the Carrum Swamp and possibly under Port Phillip. This question is dealt with more fully under the section describing the faults and fault-scarps.

The Nillumbik Peneplain.

This comprises the Yarra Plateau and the Croydon Senkungsfeld, parts of the same form, but at different levels. Sufficient observations have not yet been made to adequately discuss the cause of the movements which have brought about these different levels.

Prof. Gregory regards the Yarra Plateau (as defined by him) as a peneplain. That it is so, and also in its widened definition, may be seen on looking from any elevated point commanding a comprehensive view of the country. One of the best of such view-points is Garden Hill, at Kangaroo Ground.

Within the boundaries of this peneplain is included the coastal plain stretching eastward and south-eastward from Melbourne. This coastal plain consists of marine and fresh water tertiary sands and gravels, laid down upon the denuded, even surface of the silurian rocks whilst the more inland country was being reduced to a peneplain continuous with that on which the sands and gravels were deposited. Thus the true peneplain to the north merges into the coastal plain, and there are thus two physiographic forms, but for convenience both are grouped together as the Nillumbik Peneplain.

This peneplain rises gradually to the north and east from sea-level to varying heights, in its central portions being from 400 feet to 700 feet in elevation, according to its position in the area.

The peneplain as here defined is apparently that referred to by Prof. Skeats (3, p. 189) as formed at a level of only a few hundred feet above sea level. He regards this peneplain as being formed through the softer sediments being easily base levelled, and the more resistant dacites preserving remnants of an older peneplain, to which he also refers.

The Nillumbik Peneplain seems to die out to the east about the Steel's Creek country, and pass into that of an earlier cycle of erosion, to which, as previously noted under the description of the Yarra Plateau, the valley of the Yarra east of Warburton also belongs. Until more observations are made, however, the possibility of faulting along some of the boundaries of the Nillumbik Peneplain and the higher lands (for example at Bear's Sugar Loaf) cannot be altogether excluded. This, however, would not affect the character of the Nillumbik Peneplain, which is a true river-made plain, but would affect the amount of vertical denudation between the present Nillumbik Peneplain and the high land by which it is bounded.

The Faults and Fault-Scarps.

Two strongly-marked faults have been definitely traced.

The first—named the Brushy Creek Fault—forms part of the western boundary of the Croydon Senkungsfeld. It commences at about the Dandenong Creek to the west of Bayswater railway station, and runs north-eastward to the west of Croydon railway station as far as Burt's Hill; thence a little to the west of north, forming the western side of the Brushy Creek valley, to the Yarra River at the mouth of the former stream. This fault is about eight miles in length, and forms a prominent scarp in the landscape. It is worthy of observation that it follows the strike of the silurian rocks, which here on the west are in part somewhat quartzitic sandstones. The nature of the silurian rocks immediately to the east has not yet been determined, but possibly the earth found relief

between a fairly hard and a softer band, following the strike of the rocks. It may here be stated that the difference in hardness between the rock-bands mentioned is quite insufficient to account for the existing topography.

South of the Dandenong Creek, the Brushy Creek Fault cannot be traced. If, however, a line be drawn south-westerly in continuation of the fault to about Springvale, it will be seen that while the general level of the country along this line gradually descends to the south, it also appears to steadily drop to the east, until the low ridges and flats of Bayswater and Scoresby are met with. Thus the fault seems to die out and become replaced by a gentle tilting approaching a slight fold. This idea is supported by the decreasing throw of the fault when traversed from north to south.

The second fault, which may be referred to as the Yarra Fault, runs north-easterly from the northern end of the Brushy Creek Fault to about two miles to the north of the Yarra at Yarra Glen. It constitutes a boundary of the Croydon Senkungsfeld. Its length is about nine miles, and it keeps close to and is practically parallel to the Yarra River. It is on the right side of the stream, except as will be noted later.

This fault also has a very prominent and practically unbroken scarp.

The difference in height at various points (e.g., at the mouth of Brushy Creek, about 200 feet, at Croydon abut 140 feet, and at the "Kopje" about 85 feet), between the Yarra Plateau and the Croydon Senkungsfeld, indicates approximately the throw of the Brushy Creek Fault, whilst similarly the throw (about 200 feet) of the Yarra Fault is indicated at the Yering Gorge.

The nature of the other boundaries of the Croydon Senkungsfeld have not yet been ascertained, but from casual examination there appears to be a strongly marked but broken scarp running from north of Yarra Glen (a little above the junction of Steel's and Dixon's Creeks), eastward towards Healesville. This scarp is probably due to a fault. Faults on each side of the Yarra north of Killara, one along the edge of Mt. Toole-be-wong, and the other on the eastern side of the Warramate Hills, probably account for the depression here.

Definite conclusions on these points must await further examination.

A careful examination of the country along the western edge of the Dandenong Ranges has not been made; so that the nature of the junction here between the Croydon Senkungsfeld and the mountains has not been determined by personal observation.

I have however come to the conclusion that it is extremely probable that such junction is a fault, and that from the following considerations:—

If the eastern boundary of the Croydon Senkungsfeld along the western edge of the Dandenong Ranges be continued in the same (south-westerly) direction, it will be found to pass along the western edge of the granodiorite at Dandenong, along the eastern side of the Carrum Swamp, and along the eastern side of Port Phillip Bay to the Nepean Peninsula. This line it will be noticed, is on the western edges of the granodiorite of Mts. Eliza and Martha and Arthur's Seat, which are so sharply defined along the coast.

Selwyn in 1857 (9, p. 33) stated that a fault extended in a direct line from Frankston to Arthur's Seat, parallel to the coast. This line is included in the line above noted, stretching from the Dandenong Ranges to the Nepean Peninsula.

As already stated, the Brushy Creek Fault appears to pass southward into a gentle tilting or folding, which enables the western boundary of the Croydon Senkungsfeld to be traced (in continuation of the Brushy Creek Fault) towards about Springvale. If from the latter place the line be continued in the same direction, it will be found to pass through Mordialloc, which is at the western end of the Carrum Swamp.

There is no reason to doubt that Selwyn's fault line is a true fault. It bounds, as Mr. Hart has pointed out (10, p. 257), the granitic areas of the district; its continuation to the north-east bounds the depression of the Carrum Swamp, and also the igneous rocks of the Dandenong Ranges. West of the latter a Senkungsfeld exists. There seems little doubt therefore that a strongly marked and remarkably straight fault exists from the northern end of the Dandenongs to Dromana, a distance of nearly 50 miles. This fault may appropriately be

termed the Dandenong Fault. Whether this fault crosses the Nepean Peninsula cannot at present be stated.

A continuation south-westerly from Dandenong of the Croydon Senkungsfeld would account for the depression of the Carrum Swamp, and perhaps for the indentation of Port Phillip from Mordialloc nearly to Sorrento. It also indicates a valley extending from the Yarra at Brushy Creek mouth through Croydon, Dandenong, the Carrum Swamp and, possibly, under the waters of Port Phillip Bay, and dating from the time of the uplift of the Nillumbik Peneplain. As will be subsequently shown, the Yarra does not appear to have ever occupied this valley.

The Dandenong Fault may be a line along which repeated movement may have taken place; but we are here only concerned as to its effect in the formation of the Croydon Senkungsfeld.

Dr. Hall (11, p. 204) apparently holds that the part of the Dandenong Fault indicated by Selwyn was formed during the drowning of the lower parts of the Yarra and other streams, and the formation of Port Phillip Bay. The fault however appears to date back at least to the uplift of the Nillumbik Peneplain, the time of which is subsequently discussed, and which was long prior to the formation of Port Phillip.

The Dandenong Fault and the boundaries of the Croydon Senkungsfeld around the great mass of acid igneous rocks forming the Dandenong Ranges and adjacent hills, suggest that these igneous masses and those of Mounts Eliza and Martha and Arthur's Seat are horsts.

Mr. Griffith Taylor (12) and Mr. C. A. Süssmilch (13) have explained some of the New South Wales topography by faults and Senkungsfelder. The writer's conclusions as to the origin of the topography dealt with in this paper were arrived at before perusing these interesting papers.

The Yering Gorge.

It has been stated above that the Yarra Fault mainly keeps to the right bank of the Yarra River. An exception occurs about two and a-half miles (in a direct line) to the east of the

mouth of the Brushy Creek in the form of a deep, narrow and isolated gorge of the river about a mile in length. Its entrance and its exit are bounded by broad flats.

This gorge throws a flood of light upon the history of the topography of the country, and I have therefore given it a distinct name—the Yering Gorge. Its significance will be subsequently discussed.

The Mitcham Axis.

The southern boundary of part of the Yarra Basin may be regarded as a line running from the north of Camberwell to Burt's Hill. This is not strictly correct, as this line has been shown by Mr. Thiele (7, p. 103) to have been breached by the Mullum Mullum Creek. Gardiner's Creek is also an anomaly. The effect of the latter has probably been to divert the waters of Main Creek and adjacent streams to the Yarra instead of directly to the sea. This will be subsequently discussed. For the purposes of the argument the dividing line, as stated above, may be accepted.

This line keeps fairly close to the Lilydale railway line from Camberwell to Mitcham, and then runs more to the north in a north-easterly direction.

Between Croydon and Lilydale the water-parting between the Yarra and the Dandenong Creek Basins is more irregular, and it loses something of the ridge-like character indicative of the western portion. The low ridges however about Croydon and Mooroolbark appear to have northerly and southerly slopes as if the dividing line were originally continued between these places. All the drainage to the north and east of Lilydale enters the Yarra.

The country along the line between Camberwell and Burt's Hill gradually rises. About a mile north of the Canterbury railway station it is 380 feet, at the Surrey Hills reservoir it is 420 feet, and at Mitcham over 500 feet above sea level. At Burt's Hill—i.e., on the Yarra Plateau, at the base of this hill —it is by aneroid determination about 560 feet above sea level. It is convenient to refer to this line as the Mitcham Axis.

This axis may be a true crustal deformation formed during the differential uplift of the Nillumbik Peneplain. Whether it is so or not as regards the northern and southern slopes, there seems to be no doubt that its gradually increasing elevation eastward is due to earth movement. At Burt's Hill the rocks snapped, forming the Brushy Creek Fault.

The axis, if wholly due to crustal movements, really forms an elongated dome, truncated at its eastern side.

The general uplift of a wide area of country had given a southerly slope to the Yarra Plateau from the foot of the Main Divide, and this slope met the northern slope from the Mitcham Axis somewhere about the course of the present Yarra (west of Brushy Creek). The axis therefore determined to some extent at any rate the course of the Yarra, and fixed the boundary line between the basin of that river and that of the Dandenong Creek.

At Mitcham and eastward to Burt's Hill at Croydon, the northern and southern slopes can be clearly seen from the axis. Farther west however the slopes are less in grade, and therefore not so distinct. About Box Hill the axis is a broad level stretch of country, in which streams have in their head waters incised themselves in a westerly direction. These streams, however, in their lower courses flow, as a rule, to the north or the south.

The evidence as to the warping of the country along the Mitcham Axis is not based on the structure of the underlying rocks. No definite results can be obtained from them. It is based on the slopes of the ridges to the north and south of the axis, particularly at Mitcham and Burt's Hill, on the gradual rise of the axis from west to east, and on the slope of the country west of Bayswater being towards the east, whilst some of the streams run westerly, as will be subsequently noted.

The amount of fall along the ridges has not been determined; but those extending from the Mitcham Axis northward to the Yarra appear to have a gentle slope until the Yarra is approached, when they dip sharply towards the river, the sharp dip being clearly due to denudation. It is difficult however to see how denudation since uplift could have produced the main

slopes of the ridges. Moreover, the actual position of the axis appears to be that of an original water-parting. Were this due to denudation since the last great uplift, we should expect much more irregularity in its outline than at present exists.

In addition, differential uplift is indicated by the formation of the Croydon Senkungsfeld.

It is possible however that the slopes to the north and south of the Mitcham Axis may have been formed prior to the last great uplift, and not disturbed by that movement. This aspect will be dealt with under the section describing the monadnocks of "Pinemont," Croydon Hill and Burt's Hill.

The Slow Uplift of the Nillumbik Peneplain and the Former Character of the Yarra River.

The last great uplift of the land that took place was the elevation of the Nillumbik Peneplain. We have seen from the evidence of the Mitcham Axis and the Brushy Creek and Yarra Faults and their scarps, that such uplift was differential. The Yering Gorge furnishes us with evidence that the uplift was also extremely slow and gradual.

The river here pierces the scarp and hence the gorge. At its entrance and its exit, the gorge is bounded (on the left side of the river) by an alluvial flat. Between the two flats, the scarp descends on to a long, low ridge which steadily rises in a south-easterly direction. The scarp of the Yarra Fault is here about 200 feet above the low ridge at its base, and this low ridge is about 70 feet above the river. Taking a section in a south-easterly direction, there is first the Yarra Plateau, then the deep, narrow Yering Gorge, then the fault scarp descending to a low ridge, and then the latter rising gently towards the south-east. The plan and section of this part of the country accompanying this paper illustrate the matter.

It is clear that the river could not have formed the gorge while the country possessed any resemblance to its present contour. It is equally clear that if the Yarra Fault Scarp had been rapidly formed, the river could not have cut the gorge, but must have taken the then lowest part of the country—viz.,

that at the foot of the scarp on the low ridge above mentioned. The only feasible explanation is that the Yarra here is an antecedent river, that its course, when the Nillumbik Peneplain possessed a generally even surface at its base-level of erosion, was the same as that now occupied by and near the Yering Gorge, and that the uplift of the peneplain and the formation of the faults were simultaneous; and yet so slow that in spite of the differential movement the river held its course, and cut through the higher country as fast as the latter was uplifted.

Hence the formation of the Yering Gorge as an entrenched meander and the revival of the river. Apart from the gorge, the river occupied the Yarra Senkungsfeld, and so maintained in the depressed area the features of an old river.

The conformation of the country at the mouth of Brushy Creek also supports this view. It is at this point that the scarps of the Brushy Creek and Yarra Faults meet. The Yarra Fault Scarp here descends steeply, as at the Yering Gorge, to a low ridge. This ridge forms the right side of the Brushy Creek valley, and it is comparable to that described at the Yering Gorge. The top of the scarp is about 200 feet above the ridge, and the latter is about 50 feet above the river. The latter a little above its junction with Brushy Creek is bounded on the right side by the Yarra Fault Scarp, and on the left by an alluvial flat. Instead of cutting through the low ridge and thence running south along by the Brushy Creek Fault Scarp, it pierces the Yarra Fault Scarp and its valley becomes a deep gorge.

Unlike the Yering Gorge, this gorge continues through the Yarra Plateau to Templestowe.

As Warrandyte is the most central portion of this gorge, it is convenient to refer to it as the Warrandyte Gorge.

Although antecedent on entering this gorge, it appears doubtful whether the course of the Yarra through the Warrandyte Gorge as a whole is the same as that prior to uplift. Great bends are numerous, and, judged by the maps alone, suggest entrenched meanders. These would be expected on the slow uplift of a meandering stream. Close observation however along the whole length of the gorge shows that these bends

cannot be regarded as entrenched meanders; but are normal bends developed apparently entirely since the uplift. An attached map shows the present course of the river, and that initiated at the commencement of the uplift. The initial course is very straight, and meanders are conspicuous by their absence. Moreover, each bend is characterised by a long, gradually descending spur on the inner side of the curve showing that the bend was formed concurrently with the vertical erosion of the stream. Were the bends entrenched meanders, we should expect a curve carrying on its inner side, first a broad elevated patch around which the stream originally meandered, and then the long, sloping spur due to concurrent lateral and vertical erosion; but in every case the elevated patch is absent.

The bold bends of this gorge are explicable on the theory of slow uplift. The elevation was fast enough to allow continuous vertical erosion; but at the same time, slow enough to permit the river to curve extensively. Had the uplift been rapid, and could the river have adopted the same initial course as that already referred to in the portion now under discussion, then it seems fairly certain that the prominent bends so characteristic here would not have been developed. So far as observed, there is no evidence in the country drained by the Upper Yarra and the Dandenong Creek of any pauses or minor subsidences during the main uplift; but the purely lateral erosion at the extreme ends of some of the curves in the Warrandyte Gorge, as indicated by some alluvial flats, seems to indicate that the uplift has not continued right to the present time.

The exact position of the old course of the Yarra cannot be indicated. East of the Brushy Creek it did not apparently cross the line of the Yarra Fault Scarp (except at the Yering Gorge), otherwise further gorges would be in evidence. To the west of the Brushy Creek, its course is antecedent for a short distance, but beyond that it cannot be distinctly traced.

It is interesting to note how the Yarra River keeps close to the Yarra Fault Scarp. If the sag of the depressed area were greatest close to the scarp, as it appears without doubt to be, then whatever the original course of the stream in the depressed area may have been, as the slope towards the scarp

became more pronounced, the stream in the course of its meanderings would be forced nearer the scarp.

With the reservations mentioned, the observations now recorded confirm Prof. Gregory's view that the Yarra is an antecedent and a revived stream.

The broad depression running south through Croydon and Dandenong suggests at first sight that this may have been the old course of the Yarra, and that another stream (the present Yarra west of the Brushy Creek) worked its way eastward and captured the old river at the mouth of the Brushy Creek.

There appears, however, to be little doubt from the evidence of the Yering Gorge and the general contour of the country, that such depression is a true Senkungsfeld, and if this be admitted, the argument as to the Yarra having originally run through such depression falls to the ground, because such argument is naturally based on the assumption that such depression is river-made.

An interesting conjecture may be made as to what would have happened had the uplift of the Nillumbik Peneplain been rapid instead of gradual, and if at the same time such uplift had the same differential characters. The ridges forming the Senkungsfeld descend from Croydon and Lilydale to the north; and therefore a considerable lake would have been formed until drained through at the lowest point of the basin. The slow uplift however prevented the formation of a lake.

It may be pointed out that Prof. Gregory does not refer to the Yering Gorge. He remarks that the river turns off into the hilly country known as the Christmas Hills, and flows in a deep gorge through them to the plains near the Plenty River. This is evidently the Warrandyte Gorge. Had he observed the former gorge, it seems certain from its strong confirmation of his views that he would have cited it. It is however easily missed, unless the river be actually followed. Looked at from a distance—e.g., from near the Brushy Creek mouth—the river seems to flow uninterruptedly through low flats and ridges, bounded on its right side by the apparently unbroken Yarra Fault Scarp.

In passing, attention may be drawn to the fact that although comparatively little known, the Warrandyte Gorge

possesses some of the most beautiful scenery along the Yarra. It has a magnificent series of great bends (of which Pound Bend at Warrandyte is the largest and most impressive), as well as imposing cliffs, long quiet reaches and numerous rapids. Abundant vegetation also fringes the river.

It might be argued that the Croydon Senkungsfeld is due to direct subsidence, and not to differential uplift. This would imply uplift of the Nillumbik Peneplain as a whole, and then subsidence of the Senkungsfeld. This subsidence, if following closely on the uplift, must have been extremely slow—so slow in fact that the Yarra could erode the Yering Gorge, although the latter is in the higher country. Had subsidence been faster than the river erosion, the stream must have been deflected to the lower country, and the Yering Gorge would not be in existence. That the uplift was also slow is evidenced by the great bends of the Yarra in the Warrandyte Gorge.

Moreover, if subsidence occurred, it would not be expected that a series of ridges and valleys (although of little respective height and depth), such as are found in the Senkungsfeld, would be formed; but rather that an even floor on which alluvium would accumulate, would result.

Another view might be that the whole country was evenly uplifted, that the Yarra cut a young valley similar to the Warrandyte Gorge, throughout its length, and that a recent rapid subsidence is responsible for the Senkungsfeld. From this standpoint, the river-bottom (outside the Yering and Warrandyte Gorges) would be much below that of these gorges; a long, narrow winding lake would be formed, and the drainage would be altered. No evidence of the lake, or of its filling up, or of the diversion of the drainage, has been obtained, and so this view may be dismissed.

Taking the points mentioned into consideration, and also that direct subsidence means two distinct movements—the uplift of the peneplain as a whole and the subsequent depression of a part—for which there is no evidence; also that both movements would be very slow; and also that the one differential uplift meets all the facts of the case, there seems no reason to introduce a second movement, and, therefore, in this paper, the one movement—differential uplift—is adopted.

The Origin of the Yarra Flats.

These flats are part of the Croydon Senkungsfeld, and their explanation follows from the preceding discussion. Differential and slow uplift, resulting in the river cutting through the higher land as fast as the latter rises, means slow vertical, and consequently, strong lateral, erosion in the lower ground. Thus, wide shallow tributary valleys and extensive alluvial flats, through which the main river meanders and builds up a flood plain, are formed.

This has apparently happened in the area in question. During the excavation of the Yering George, the river cut as fast as the land rose. There has, therefore, been no time for lateral erosion, and the valley here remains a gorge. In the depressed area above the Yering Gorge, the stream was constantly reaching a temporary base-level, waiting for the erosion of the gorge. This gave great play to lateral stream erosion and atmospheric denudation, with the result that the low ridges have been cut into wide shallow valleys by the sluggish tributary streams, and the Yarra itself in its meandering course has formed the wide alluvial flats of Yarra Glen, Killara, etc.

The excavation of the Warrandyte Gorge has caused the same result. The distance however between the exit of the Yering Gorge and the entrance to the Warrandyte Gorge is short, so that the effects are on a smaller scale. The broad, flat-bottomed valley of the Brushy Creek owes its characteristic features to the same cause.

The Antecedent Character of the Dandenong Creek and Tributaries.

The general characters of the Dandenong Creek have been described above, and the slight tilting or dip to the east of the Yarra Plateau in the Dandenong Creek area was referred to.

The Dandenong Creek has generally a southerly direction, but instead of running south through the lowest part of the Croydon Senkungsfeld, which would appear to be its natural course, it passes into the higher country to the west, but works its way well into the Senkungsfeld again near Dandenong.

The main upper branch of the Dandenong Creek and the Blind and Corhanwarrabul Creeks have a westerly course, which is in opposition to the slope of the country. The upper parts of the Dandenong Creek are also characterised by the extensive flats at Bayswater, while lower down-stream, the valley contracts and possesses the normal characters of somewhat sluggish streams. The same remarks apply to some extent to the Blind Creek, and apparently also to the Corhanwarrabul Creek, but as the valley of the latter has not been fully examined, some reservation must be made with regard to this. This creek is not so important, as probably almost the whole of its lower course is within the boundaries of the Senkungsfeld.

It is difficult to understand how on a rapid uplift such courses could be formed; the only explanation appears to be that the streams are antecedent, and that the uplift being gradual, they were able to maintain their directions notwithstanding the opposing movement. As they have deepened their channels, they are also revived streams.

It will be noticed that no tributaries join the Dandenong Creek from the west, whilst those from the east are well developed. This is explicable, both from the present contour and from that prior to uplift. The Dandenong Ranges having a greater rainfall and a considerable area of high land, supply a fair volume of water to form watercourses, and hence the growth of the eastern tributaries. To the west of the Dandenong Creek, there is little ground not occupied by other drainage systems, and the country is at a low elevation. No tributaries of any consequence can therefore be expected from the western side.

The Origin of the Bayswater and Scoresby Flats.

The facts set forth as to the contour of the Dandenong Creek area furnish an explanation of these flats as well as show the antecedent character of the streams.

The flats referred to occur to the east of the Brushy Creek Fault Scarp, and towards the eastern end of the gentle tilt or dip farther south. As previously remarked, the Dande-

nong Creek and its tributaries kept their courses during differential uplift. That being so, the upper parts of the streams in the depressed ground would reach temporary base-levels, whilst the lower portions were still vertically eroding, and lateral erosion would therefore be active in the upper parts, tending to form wide alluvial flats and shallow open valleys. Down-stream the valleys would be more contracted, owing to vertical erosion being for the time the main occupation of the streams.

The origin of these flats may be explained in the following way.

Treating first of those flats near the head of the Dandenong Creek, which I have referred to as the Bayswater Flats, it is found that the creek here divides into several branches. The main stream runs westerly from the Dandenong Ranges. A branch runs southerly from Croydon, meeting the main stream at Bayswater. Two other small streams run south-westerly and north-westerly to the Dandenong Creek at Bayswater. Each of these small streams has formed rather extensive alluvial flats, but after they have joined together at Bayswater, the valley becomes narrower and the wide flats are absent. It is to the west of Bayswater that the higher land of the Yarra Plateau occurs, and therefore the explanation that the flats are due to slow and differential uplift seems the most feasible.

In the tributary running from Croydon, the flats are not so extensive as those more to the east. This may be explained (at least in part) in the following way:—The Croydon tributary is short, is in low ground, and has little drainage to work upon. Hence its denudation will not be very great. The main stream however of the Dandenong Creek rises in the high Dandenong Ranges, where there is an abundant rainfall, steep fall and fair area drained. The result is much greater formation of alluvial flats.

The change from the flats to the more normal type in the Dandenong Creek is not so marked as in the case of the Yarra. The transition is more gradual. This appears to be due to a more gradual change from plateau to Senkungsfeld in the Dandenong Creek area. A feature that appears to corroborate the explanation offered of the Bayswater Flats is the higher and steeper aspect of the right bank of the Dandenong Creek

as compared with the left. This is well seen where the creek to the west of Bayswater runs westerly and then southerly.

At Wheeler's Hill, a prominent point on the Fern Tree Gully Road, and on the western side of the Dandenong Creek, the ridges on the eastern side are so low compared with this hill that a fault scarp for a limited distance is here suggested again, rather than the gentle tilt or dip. This, however, is not clear. Wheeler's Hill appears to rise some distance above the general height of the Yarra Pleateau in this locality, and this may account for the apparent discrepancy.

The Blind Creek has some flats towards its head, and although apparently confirmative of the suggested origin of the Bayswater and Scoresby Flats, they are hardly distinct enough compared with the lower portion of the stream to warrant any definite conclusion being drawn. This indefiniteness may be due to the head waters of the creek not penetrating (according to the current maps) the Dandenong Ranges, and hence not gaining that supply of water and force required to form the flats.

The Corhanwarrabul Creek seems to be a similar case to that of the main upper portion of the Dandenong Creek, and the wide flats at Scoresby may probably be explained in the same way as the Bayswater flats. The Ferny and Monbulk Creeks (affluents of the Corhanwarrahal Creek) have cut back well into the mountains, which have furnished sufficient water and force to produce the flats. The Corhanwarrabul Creek valley has not been observed very much, so that stress cannot be laid on its apparent history.

Once differential movement is allowed during uplift, then, in addition to the more prominent features determined by such uplift, minor distinctions may arise, and it is possible that the Bayswater and Scoresby Flats are due in part to this cause. At the same time the explanation given above appears to meet the facts without any other hypotheses.

There is a depression beween Mitcham and Ringwood. This was formerly occupied by a branch of the Dandenong Creek, but as shown by Mr. Thiele (7, p. 103), its head waters have been captured by the Mullum Mullum Creek, and diverted to the Yarra.

The Age of the Nillumbik Peneplain.

Dr. Hall (14, p. 64) inclines to the opinion that the tertiary sands and gravels of Camberwell and adjacent districts are of fresh water origin, and of the same age as the marine beds at Beaumaris, that is, Kalimnan, and with this view the writer agrees.

These fresh water beds rest upon the surface of the Nillumbik Peneplain, and therefore would be deposited in the main after that portion of the peneplain on which they are deposited had been formed; it follows that the period of planation of the peneplain as a whole was during or prior to Kalimnan times.

The uplift of the peneplain probably dates therefore from late Kalimnan time or its close, and it has continued apparently to very recent times, with vibrations (to use a graphic term employed by Mr. E. C. Andrews) at the south-western end of the peneplain.

The Barwonian and Kalimnan series of rocks are generally regarded as of eocene and miocene age respectively. Recently the miocene age for the Jan Jukian, a subdivision of the Barwonian, has received support from an examination of certain groups of fossils by Mr. F. Chapman (15, p. 311).

The Kalimnan, which are admitted by all authorities to be younger than the Jan Jukian, will, if Mr. Chapman's views as to the age of the latter ultimately prevail, have to be removed to a later period, presumably the older pliocene.

I cannot express any opinion as to the ages of the rocks in question, from a palaeontological standpoint, but I would point out that from a physiographic point of view, the more recent age would be more acceptable; as, assuming that the Nillumbik Peneplain was completed during Kalimnan times and uplift then commenced, the erosion by the Yarra seems little advanced for a stream working from the close of the miocene time, especially when the erosion of the lower Yarra since newer basalt time is considered.

No definite statement however can be made on the point, and the fossil evidence will of course have ultimately to determine the question, but where the palaeontology is conflicting or interpreted by different authorities in different ways, then it

is well to bear in mind the possible service that physiography may render.

The Growth of the Yarra.

A glance at a map of the Yarra and its tributaries will show that the present main stream consists of various parts which have not always formed sections of the principal river of the area. From the nature and disposition of the rocks and the general configuration of the country, the growth of the Yarra would appear to be as outlined below.

As far up stream as Healesville, the Yarra is simple, and since the inception of the present topography—i.e., since the formation and uplift of the Nillumbik Peneplain—it has apparently been the main stream. At Healesville there is a sudden break. From a direction east and west, it changes to one north and south. The latter is not its natural continuation. The Watts River is really this. The present Yarra from Healesville to its junction with the Woori Yallock Creek, together with the latter, was no doubt at one time a tributary, but as it developed more rapidly than the Watts, the latter became the tributary and the former the principal river.

The reason of such greater development is obvious. The Watts River had the hard rocks of the dacite and granodiorite area to the north and north-east of Healesville to erode, and the Acheron, a strong affluent of the Goulburn, cutting back towards the Watts through soft silurian strata. The southern tributary of the Yarra had a wide and long area of similar silurian rocks to work upon. Hence erosion here was rapid, and the stream quickly cut its course backward and southward. The present Woori Yallock Creek was one of the upper arms of this stream, the other being the existing Yarra, east of the Woori Yallock junction to the Yarra Rivulet (or Little Yarra) and the latter itself. Most of this second arm is also in silurian country.

The present Yarra for some distance east of the Yarra Rivulet would be a weak tributary of this second arm, its weakness being due to the bar of hard igneous rocks at Warburton through which it would take long to cut.

Both the arms referred to ultimately reached in their head waters large areas of igneous rocks (with the exception of a narrow strip of silurian at the head of one of the branches of the Woori Yallock Creek, and which has apparently not favoured the latter, probably on account of a struggle with a south-flowing stream). These igneous rocks, from their great hardness, would act as a check upon the erosive activities of the Woori Yallock Creek and Yarra Rivulet. Meanwhile the Warburton tributary was steadily cutting its way between the dacite and granodiorite of that district. Behind (to the east of) these igneous rocks was a great area of silurian country, which if completely tapped, would greatly add to the volume of the stream. The igneous bar at Warburton is very narrow, compared with the width of the other areas of igneous rocks in the Yarra Basin. This gave the Warburton tributary an immense advantage over the other streams that were struggling for the predominant position. The bar was cut through, leaving the present narrow gorge at Warburton, and the river then rapidly eroded backwards. While the gorge was being eroded in the igneous rocks, lateral erosion was proceeding in the silurian area farther up-stream. This has continued, until, at the present time, there is the narrow gorge in the igneous rocks, with the short torrential mountain streams, whilst up-stream we have the more open valley with long, well-graded tributary streams.

The Warburton tributary therefore gained such an accession of strength that it rapidly became the present main stream, with its outpaced competitors subordinated to it.

The history here outlined probably commenced in the cycle of erosion prior to that originated since the uplift of the Nillumbik Peneplain.

Prof. Gregory has suggested that the Acheron and Watts Rivers were originally one stream passing through the Beenak Gap, and that the Acheron part was captured by the Goulburn, whilst the Watts and its southern continuation were captured by the Yarra. This question is outside the scope of the present paper, but it may be remarked that this could only have taken place when the whole country was at least as high as the Beenak Gap. This is probably what Prof. Gregory refers to

when he states that the south-flowing stream passed over the Beenak Gap probably at a time when the surface of the country was some 600 feet higher than at present (1, p. 113).

If Prof. Gregory's view be correct, the Yarra would not be the main stream until the capture of the various north and south streams mentioned by him. By the time however the Nillumbik Peneplain was formed, there could be no doubt that it was the principal river of the area. The conditions previously stated would therefore hold good in its future development; and I see no reason to doubt that such development was on the lines above suggested.

The Influence of Hard Rocks in the Evolution of the Topography.

The remarks made on the complexity of the Yarra illustrate this subject very well. A wider comparison is also available, and may now therefore be discussed. Such discussion, however, is almost entirely based on the map to be presently referred to, and not as the result of much personal observation.

It is proposed to compare the Yarra Basin with adjoining basins, and principally with that of the Upper Goulburn. The latest geological map of Victoria (a portion of which with some details omitted and an alteration of the boundaries of the basins near Mt. Baw Baw, is reproduced) shows, as of course is well known, that the Main Divide runs east and west, and the principal streams consequently to the north and south. Notable exceptions to this general rule are the Yarra and the upper portion of the Goulburn. These are east and west streams. It is also to be noticed that as the Main Divide approaches from the east Mounts Howitt and Buller, it becomes forked, the northern prong extending through Mount Buller, Tabletop, the Strathbogie Ranges, and thence to Trawool. The southern prong runs south from Mount Howitt to a little north of Mount Useful, and thence westward through Mounts Matlock, Arnold and St. Leonard to Mount Disappointment.

The southern prong is the actual Main Divide, and is along the northern boundary of the Yarra Basin. The Upper Goulburn has an opening at its western end connecting with the

country farther north, thus throwing that basin into that of the Murray. The term Upper Goulburn Basin is here restricted to that portion of the general basin, east of Trawool, bounded by the two prongs mentioned above.

The Yarra and Upper Goulburn Basins are largely bordered by old igneous rocks (dacites, granodiorites and porphyries), generally of much greater height than the surrounding country. These rocks are arranged roughly in three prominent parallel east and west bands, a feature which does not occur elsewhere in Victoria. These bands form respectively the northern boundary of the Upper Goulburn Basin, the boundary between the latter basin and that of the Yarra, and the southern boundary of the Yarra Basin.

It will I think be admitted that the present basins of the Yarra and Upper Goulburn and their divides are clearly determined by the outcrops of the igneous rocks mentioned, and that such basins have been blocked out by differential denudation, as suggested by Prof. Skeats (3, p. 189). Faulting may possibly have assisted; but denudation was probably the chief factor.

Assuming this to be correct, the size and form of the drainage areas become intelligible. The Yarra Basin is much smaller than that of the Upper Goulburn Basin, but this is not due to some mere chance. The hard rocks have determined the areas, subject to some favourable circumstance increasing one at the expense of the other.

Coming to greater detail, the Yarra Basin is bounded on the north by the granodiorite of Mt. Disappointment, by silurian rocks, and by the great mass of dacite and granodiorite forming Mts. St. Leonard, Arnold, Juliet, etc. The dacite of the Dandenong Ranges and the granodiorite stretching eastwards from these hills towards Baw Baw, form the southern boundary. The igneous rocks of the two boundaries mentioned are connected by the narrow bar of similar rocks at Warburton.

The effect of this bar has already been discussed when treating of the growth of the Yarra, and it seems reasonable to maintain that had no such bar existed the basin of the Yarra eastward would probably have been greater in area than

it is at present, especially in view of the short course of the Yarra to the sea. The bar however retarded denudation, and enabled the rivers of the adjoining basins to annex territory that otherwise would have been occupied by the Yarra.

In support of this proposition, attention may be drawn to the boundaries of the Upper Goulburn Basin, which, except in the east and south-east are igneous rocks. In the south-east corner, the basin abuts on to those of the Yarra and of the Thomson. The rocks here and for some distance north and south are ordovician and silurian sediments, and are practically homogeneous in character.

A struggle for supremacy (on even terms as regards the character of the rocks at their head waters) has taken place between the three basins mentioned; and, although the Yarra has the shortest course to the sea, yet its small drainage area and consequent less rapid erosion, together with the retardation due to the igneous bar at Warburton, have not enabled it to contest for territory successfully with the other basins. The battle has therefore been principally between the Upper Goulburn and the Thomson Basins.

On present knowledge the line of the original divide in the district of the head waters of the Goulburn and Thomson Rivers is unknown, but from the present divide's tortuous course, it may be safely asserted that it has been subjected to much shifting. It would appear, however, from the general direction of the divide, that it was, in the district mentioned, much further north than at present; and that by reason of the soft rocks and the greater drainage area, resulting in the rapid approach to base-level in its lower portion, and consequently greater power of erosion in its head water streams, the area of the Goulburn Basin has been increased at the expense no doubt of the Thomson and Yarra Basins. Whatever may have been the actual history, if a fairly wide band of dacite and granodiorite had stretched as a bar from Mt. Torbreck to Mount Buller, part or most of the south-east corner of the Upper Goulburn Basin may not have been included in such basin.

The fact that the Thomson and Tanjil Rivers, as shown by Messrs. Kitson and Baragwanath, Jun. (16, pp. 86 and 87), ap-

pear to have beheaded the upper portions of the Yarra does not invalidate the conclusions stated as to the cause of the limitation of the Yarra Basin, but suggests that this basin was at one time a little larger than at present, but for some possibly local reason it has been slightly reduced by capture.

Whether the Yarra will extend its territory at its head waters is difficult to answer. It has the great advantage of the shortest route to the sea, so that ultimately at any rate its upper waters should have a greater fall than those of the Thomson or the Goulburn. By this means it may possibly increase its boundaries.

As already noticed, the areas of the basins have been determined by the positions of the hard old acid igneous rocks; and the larger the basins, the greater the volume of water passing into the main river, and consequently the greater the vertical erosion of the main river and the headward erosion of its tributaries. The divides of the smaller basins are thus generally forced backwards, and such basins contracted, even in the areas of the igneous rocks. This is especially noticeable in the southern boundary of the Yarra Basin, and the northern boundary of the Upper Goulburn Basin. In the case of the former, the rivers of the great basin of Gippsland appear to have forced the divide to the north; whilst in the latter, the rivers of the Murray Basin—practically all tributaries of the Goulburn and Ovens Rivers—appear to have driven the divide almost to the southern edge of the igneous rocks.

A southward-shifting divide between the Upper Goulburn and Yarra Basins may explain (unless continued far to the north) the southerly slopes of the ridges north of the divide, which Prof. Gregory states there exist, and which slopes may not necessarily be evidence of old south-flowing streams from the north.

The Relations of Gardiner's and Main Creeks.

Gardiner's Creek is a tributary of the Yarra, and enters that stream south of Hawthorn after following a north-westerly course. Main Creek runs south-westerly from Black-

burn until it joins Gardiner's Creek near Murrumbeena. The two streams at their junction are at right angles to one another. When plotted on a map they do not appear perfectly normal to each other. A normal tributary generally joins the main stream at a more or less acute angle, and if Main Creek and the creek a little to the west are normal affluents, their courses would be expected to have a more westerly trend than their present directions. The question therefore arises whether some changes have not taken place during the development of the streams.

The general slope of the country south of the Mitcham Axis is towards the south-west. Main Creek follows this slope until it reaches Gardiner's Creek, which enters the Yarra at a normal angle. During its course, Gardiner's Creek cuts through the country between Malvern and Camberwell. According to the contour maps of the Lands Department, the country about half a mile to the north-east of the East Camberwell railway station is about 320 feet above sea level. It descends from here south-westerly to Malvern, whose highest point is about 212 feet above the same base. East of Malvern the country drops to 169 feet at Caulfield, 141 feet at Murrumbeena, and 187 feet at Oakleigh. The latter is the height of the railway station, but the country rises rapidly to the north-east and east. This high land also continues south-eastward towards Clayton township, from which a low ridge runs to the south.

The Caulfield and Murrumbeena country steadily drops in a south-westerly direction to the sea. It has been slightly eroded by small streams, but the latter have not affected the general level, which appears to be about that quoted for Caulfield and Murrumbeena.

Gardiner's Creek therefore passes from the lower country of Murrumbeena and Caulfield through the higher strip bounded on one side by Camberwell and on the other by Malvern. This, taken in conjunction with the direction of the Main Creek, suggests that the present stream disposition has not always been the same.

The following may have been the history of the streams. As the Yarra dug its course, a tributary was formed, which cut

its way backwards in a south-easterly direction. This is the present lower Gardiner's Creek. At the same time the Main Creek ran south-westerly across Murrumbeena, and thence down to the sea in a southerly or south-westerly direction, generally speaking. It was joined by the creek farther west, and, possibly, by a tributary running south-easterly, this tributary being now part of the present Gardiner's Creek.

The Yarra cut its channel quickly, and so gave a rapid fall for the short Gardiner's Creek. Main Creek had only a small drainage area; its erosion therefore would be much slower than the Yarra, and the fall would not be so great. Gardiner's Creek would tend therefore to rapidly cut backward, and possibly gradually annex the western stream, and ultimately Main Creek. The old stream south of Murrumbeena would thus be beheaded, and its upper waters diverted into the Yarra instead of into Port Phillip Bay direct. The lower valley of the old Main Creek would then be too wide for its drainage, and smaller valleys within the old valley would originate, some running towards the sea and others to the present Gardiner's Creek.

That some such series of changes has taken place is possible, but not certain.

The direction of the present Main Creek, and the creek to the west, the somewhat depressed country between Oakleigh and Malvern, and the direction of Gardiner's Creek across the slope of the country are explained by the suggestion made.

On the other hand, the denudation south of Gardiner's Creek has been so slight on account of the small drainage area and the low elevation of the ground that it is difficult to gather strong evidence of the changes. Another difficulty is Scotchman's Creek. This runs north-westerly into Main Creek, near the junction of the latter with Gardiner's Creek. It is possible that this was originally a short tributary of the old Main Creek. After capture of the heads of the latter by Gardiner's Creek, it offered a favourable channel for the backward erosion of the latter, and thus perhaps it has grown.

Another difficulty is the course of the Elsternwick Creek. This runs approximately parallel to Gardiner's Creek, and requires an explanation if the changes suggested have taken

place. Some favourable local circumstances may have brought this about.

Again, the elevation of the land in the Upper Yarra district was, as we have seen, very slow. This no doubt also applied to the land forming the area now under discussion, and if so, then Gardiner's Creek and its tributaries may be antecedent streams, but their directions do not appear normal under any circumstances.

We thus see that the question has at present to be left an open one. A more detailed examination of the country than the writer has been able to make might throw further light on the matter, and it is with this idea that the various possibilities have been here suggested.

Monadnocks.

Scattered about on the Nillumbik Peneplain are various hills rising above the general level of the peneplain. These represent the unplaned portions of the latter, and to them Prof. W. M. Davis has given the name monadnocks. The following have been recognised by the writer. There are other possible ones which I have not yet examined, and in addition there are no doubt further ones in country which I have not yet traversed. Some of the outlines of these forms are drawn on an accompanying plate.

Morang Hills.

These have been referred to in the writer's paper on the Plenty River (6, pp. 164 and 167). They were there suggested as a monadnock, and from further observations there appears to be no doubt that they form a true monadnock. Their preservation is due to the core of granite, and the indurated sedimentary rocks surrounding the granite.

Sugar Loaf Hill (Mont Park), near Heidelberg.

This is a small hill with its longer axis running north and south. It has a slightly greater elevation than the surrounding peneplain, and its projection is clearly due to the very

hard rocks of which it is composed. The surrounding rocks are soft silurian sediments. The geology of this hill presents some interesting features, and is being worked out by Mr. F. Chapman and myself.

"Pinemont," Croydon Hill and Burt's Hill.

"Pinemont" and Burt's Hill are on the line of the Mitcham Axis. This is rather a striking coincidence, but whether actually climbed, or viewed from a distance, as from near Kangaroo Ground, they appear to be undoubted monadnocks. Their occurrence on the Mitcham Axis suggests the possibility that this axis was perhaps in existence at the time of uplift of the Nillumbik Peneplain, due to being the old water-parting between the old Yarra and Dandenong Creek Basins. The antecedent character of these streams would permit of this conclusion being drawn, and as the water-parting is generally least denuded, monadnocks would naturally occur there.

In addition, even when reduced to a peneplain, gentle slopes on either side of the water-parting would exist, and might be preserved on uplift. If this be the true history of the case, then the suggested tilting to the north and south of the Mitcham Axis might not hold good. To some extent therefore this question must be left open.

Mr. Thiele (7, p. 103) has referred to "Pinemont" as a conspicuous conical hill rising to about 600 feet above sea level, and marking the position of the old water parting. This hill is a conspicuous landmark from many parts of the country. Perhaps the best view of it is from the Surrey Hills Reservoir, from which its residual character is clearly seen. It rises about 100 feet above the level of the peneplain at its base. It is difficult to account for the projection of "Pinemont" from the nature of its component rocks. These so far as visible are not appreciably different in their hardness from those of the surrounding country.

Croydon Hill occurs a little to the south of Burt's Hill. They both rise about 100 feet above the level of the Nillumbik Peneplain at their bases. The peneplain is here about 560 feet above sea-level. They are rather elongated conical hills. Their

exposed rocks are fine-grained, tough sandstones, with some quartz veins. With the sandstones are no doubt interbedded shaly rocks. The sandstones in places become almost quartzites, and in the narrow north and south belt, comprising Croydon and Burt's Hills and the "Kopje," the rocks seem somewhat more resistant than elsewhere. The greater difficulty in the removal of these hard rocks may therefore account for the monadnocks mentioned.

The "Kopje."

This is an isolated hill on the Nillumbik Peneplain, just west of the Brushy Creek Scarp, and close to the Canterbury-road. It is clearly a monadnock, and it sweeps up to a height of probably nearly 100 feet above the surrounding peneplain as a small but bold cone.

A most instructive section can be obtained here. Taking a traverse from the west of the "Kopje" we have first the Nillumbik Peneplain, then this monadnock, then the peneplain again for a short distance to the Brushy Creek Fault, where the Nillumbik Peneplain is thrown down about 85 feet. Farther east at a lower level again is the alluvial flat, through which a tributary of the Dandenong Creek meanders. Thus there are four distinct levels of country, the explanation of which may be inferred from the earlier part of this paper.

Kangaroo Ground.

This high ground is due to a small patch of basalt, which is generally regarded as older basalt. This and that capping the hills at Greensborough will be dealt with in another paper.

The basalt at Kangaroo Ground rises well above the general peneplain of the sedimentary silurian rocks (the Nillumbik Peneplain); such elevation appears to be due to the basalt having been erupted before the formation of the peneplain, and having largely resisted the general planation by reason of its superior hardness.

The Kangaroo Ground therefore forms a true monadnock, although somewhat dissected.

At the south-western end of the basalt, and just south of the main road, a sharp cone of silurian rocks rises some height above the peneplain. It is also higher than the basalt abutting, but the latter is somewhat denuded here. This hill is also a monadnock.

Lilydale Basalt and Quartzites.

These are apparently monadnocks on the Nillumbik Peneplain, which is here in the Croydon Senkungsfeld; but they have not been sufficiently examined to be adequately discussed.

Warramate Hills.

These occur about two miles to the nort-west of Killara railway station. They are marked on the parish map of Gruyere. The two chief hills are Briarty's Hill (an old Trig. station) and Steel's Hill.

At Killara the Wandin Yallock Creek enters the wide flats through which the Woori Yallock Creek and Yarra River wind towards Healesville. West of Killara the Wandin Yallock Creek is in a comparatively narrow valley, with well-defined sides. From the top of this valley the country is seen stretching away to the south-east, south and west as a fairly even, but dissected surface.[1] From this surface a ridge runs northward, steadily rising, and stretches out as an elevated tongue bounded on the north, east and west by much lower land. This ridge forms the Warramate Hills. At Briarty's Hill the ridge rises rather abruptly, the height of this hill being according to an aneroid reading about 1400 feet above sea-level, and about 1100 feet above the alluvial flats at Killara. A little to the north of Briarty's Hill is Steel's Hill, which does not appear to be so high, and from Steel's Hill there is apparently an abrupt descent. The Warramate Hills form a prominent feature in the landscape from various points of view.

The exposed rocks of Briarty's Hill are moderately tough sandstones, with abundant quartz in parts. There seems no reason why they should specially resist denudation, so as to

1 Whether this surface is part of the Nillumbik Peneplain, or not, I cannot say, as its relations have not been determined.

project to the height that they do above the plateau country to the south.

I can, however, at present assign no other cause to the prominence of the Warramate Hills, which may therefore tentatively be regarded as a gigantic (in comparison with others in the Yarra Basin) monadnock.

Subsequent research may determine that these hills are due to strong faulting of the adjacent country in times prior to the formation of the Nillumbik Peneplain; or they may for some unknown reason be the residuals of one or more peneplains.

More measurements and wider observations are necessary before coming to any conclusions as to the existence of peneplains above the Nillumbik Peneplain, and below that suggested by Prof. Skeats as on the tops of the dacite masses referred to by him; but it may be pointed out that the Morang Hills, "Pinemont," Burt's and Croydon Hills, and the "Kopje" appear to be at about the same height (somewhere about 100 feet) above the Nillumbik Peneplain. This strongly suggests that another peneplain existed at this level. The height of the Divide just to the east of Mt. Disappointment is about 1700 feet. The Warramate Hills are about 1400 feet. Connecting these two points, a third possible peneplain below the tops of the dacite rocks suggests itself.

View-Points.

A few remarks on these may not be out of place. All the monadnocks mentioned, as would be expected, constitute excellent points for observation of the surrounding country. Close to Melbourne, Sugar Loaf Hill offers a very fine panoramic view.

At Kangaroo Ground, in the basalt country, Garden Hill occurs. This is on the main road to Christmas Hills, a little east of where the latter road diverges from the Queenstown road. This hill and the adjacent basalt are almost destitute of trees, and as the basalt is well above the surrounding country, an excellent view of the latter is obtained. There is no interruption in any direction for many miles. It is from here that the general character of the Yarra Plateau is well seen.

Another fine view-point is Bear's Sugar Loaf, north of Arthur's Creek township. From the latter place, it has the appearance of a gigantic pyramid, due to its ridge-like character and sharp truncation at its southern side. Perhaps from this hill the finest view is obtained of the actual Main Divide. The configuration of the latter, with its numerous branching gullies seaming its sides, is very distinct.

The higher view-points, such as Mount Dandenong, Malleson's Lookout, Mount Toole-be-wong and others, need not be more than mentioned as they are so well known, but most of those referred to above do not appear to be much visited, although to the lover of scenery, they offer many attractions.

It might be mentioned that surmounting "Pinemont," Burt's Hill, and the "Kopje" are private houses. Permission should therefore be obtained to ascend these hills.

Rapids and Small Islands, and their Relations.

In the Warrandyte Gorge numerous rapids occur. Rapids are, as is well known, usually found in a stream, or a particular part of a stream that has not reached its grade. Streams of this nature are generally, in the language of geographers, "young," and the portion of the Yarra referred to possesses this characteristic. The valley is narrow and steep, and its bed rocky and uneven. The projecting hard rocks on the river bottom are the cause of the rapids.

These hard rocks are generally bands of sandstone which are interbedded with the softer shales. They are of silurian age, and are inclined at the moderately high angle characteristic of the silurian rocks around Melbourne. The sandstone bands are therefore parallel to the general strike of the rocks, and, as the river is constantly changing its course, the bands of hard rock, and consequently the rapids, occur at all angles to the actual direction of the river in any particular place.

As the river reaches its grade, these rapids will disappear. The river below Templestowe is fairly well graded, and rapids are generally absent.

In the same part of the river as the rapids, numerous small islands occur. They vary in size from tiny ones about a yard

in diameter to those 20 or 30 yards long. Like the rapids they are rare below Templestowe, and this fact immediately suggests a connection between these small islands and the nature of the valley in which they occur. In addition, they are found to be almost constantly associated with the rapids, and observation proves that this is not merely a coincidence, but that the cause of the rapid is also the cause of the island.

The hard rocks which form the rapids tend to project above the softer rocks, and also, at low water, above the level of the stream. These projections on their up-stream side arrest portions of the gravel sand and silt carried along by the stream. Boughs and trunks of trees floating down the river are also at times caught by the same obstacles.

The rock projections, assisted by the stranded trunks and boughs, when present, cause silting up in a small way, and a miniature island may be formed.[1] Vegetation of some kind will soon spring up, and if a strong plant such as a young shrub or tussocky grass takes root, it will increase the resisting power of the embryo island. Should the conditions continue favourable, the island increases in size and vegetation becomes stronger, until trees of moderate height, shrubs, and dense undergrowth often cover the soil and bind it firmly together.

The island thus becomes able to withstand the river, even in the winter, and becomes a definite feature of the stream. Islands in all stages of growth, from the single tussock of coarse wiry grass growing in the river, to the large island with tall trees and dense undergrowth, can be seen in the portion of the Yarra now referred to.

The formation of the island of course divides the stream into two parts, with the result that when passing the island its volume, in proportion to its space, is increased, and consequently its velocity also. The vertical erosive power of the stream is thereby accelerated, and the exposed parts of the rapids are more quickly planed down than they would be without the island. At length a temporary or permanent grade is reached, and vertical erosion ceases. Lateral erosion

1 Small islands can of course be formed by obstacles in places other than at rapids, but the latter would appear generally the most favourable position and certainly are so in the part of the Yarra here dealt with.

takes its place, and by this means the island is gradually removed, and the rocks beneath are reduced to the general level. If a temporary grade has been reached, the same process may take place several times, until the stream arrives at a permanent grade, when the islands finally disappear. Hence the absence of islands in the lower well-graded parts of the Yarra is accounted for.

In well graded streams however, as in the Yarra near Heidelberg, numerous trunks and boughs of trees collect. At first sight, this fact would appear to be favourable to the formation of small islands, but the latter are rarely present. The explanation is apparently that a trunk or bough of a tree does not usually offer the continuous bar across the stream as a whole or in part that a band of rock does. The latter retains the silt and sand collected, whilst the former, owing to its generally tilted, uneven and often movable position, allows the current to wash around it, and so remove the material that might otherwise have formed an island.

An interesting example, however, of the formation of an island through driftwood was recorded in the "Age" newspaper on the 20th of April last. This occurred at Watts Gulch, in the Snowy River, below Orbost. The island "appears to have found a beginning in some floating debris which lodged against an embedded log at very low water. It grew gradually in magnitude with fresh accumulations of silt and debris, and is now covered with a prolific growth of vegetation, including scrub and grass, binding the soil into a compact mass. Another small island has since grown up under similar conditions." The channel was becoming blocked, and the Government agreed to expend £200 in removing the islands.

The islands in the Warrandyte Gorge grow faster in the directions parallel to the stream than across it. This is obviously due to the river keeping for itself on each side of the island as wide a passage as possible, and is somewhat analogous to silt jetties in lakes.

The formation of islands must also deflect the stream in places, causing it at times to impinge on one bank more than it otherwise would do, and thus tending to increase the curves of a stream. The course of the river is often directly influenced

by the island becoming attached to the "mainland"—that is, to one side of the valley. Actual examples of growing and of completed attachment may be seen in the Yarra above Warrandyte. If the island happens to be fairly close to one side of the stream, drift wood soon collects in quantity in the narrow channel. The current becomes checked, silt is deposited, and the island gradually becomes tied to the mainland, forming a strip of alluvial land with dense vegetation. A certain portion of the river is therefore diverted, and naturally, other conditions being suitable, the stream tends to cut into the opposite bank and form a curve. This curve may influence the whole course of the river down-stream.

The writer is not aware that the connection here noted between rapids and small islands in rivers, has been hitherto recorded.

Differential Pot-Hole Erosion.

In most text books of geology and physiography, the formation of pot-holes in the beds of streams is described, and their effect in the general erosion of the valley noticed. The writer has not, however, seen it distinctly stated[1] that this mode of erosion possesses a selective action, although this is perhaps implied in the general statement that hard rocks resist the denuding agents much more effectually than soft ones. As an actual illustration of such action has been observed, the following remarks may be of some general as well as of local interest.

The example referred to occurs in a small outcrop in the bed of the Mullum Mullum or Deep Creek, at a point immediately to the north of the Deep Creek Road, which meets the stream just after its pronounced swing round from the south-west to the north-west, near Ringwood. The rocks consist mainly of shales of medium toughness in beds from three or four inches to about three feet in thickness. Interbedded with these are bands, from one inch to three inches thick, of hard micaceous sandstone. The strike of the rocks is approximately

1 The nearest approach is in R. S. Tarr's "New Physical Geography" (1909), which contains a photograph of cascades falling (presumably over hard rocks), and excavating pot-holes in shales. The two cases however are not quite parallel.

at right angles to the direction of flow of the stream at the particular part in question, and the dip is westerly at 60 deg. Numerous pot-holes occur for a distance of about 30 feet along the stream-bed. Simple holes are generally roughly circular in outline, and vary from about three inches to over a foot in diameter (this measurement often being directly proportional to the width of the shaly beds), with an average depth of about six or eight inches. In places the holes have coalesced to form compound ones, the largest of which is about four feet in longer and two feet in shorter diameter, with a depth of about two feet. The holes are mostly confined to the shales even where two thin sandstone bands are within a few inches of one another. The softer rocks (the shales) have been selected, and the sandstones have generally resisted encroachment, with the result that the enlargement and union of holes have taken place parallel to the sandstone bands. The compound holes are often therefore narrow and elongated, and together with the simple ones are generally arranged in rows parallel to the strike of the rocks. In some instances the sandstones have been pierced both by simple and compound holes, but where the diameters are unequal, the longer one follows the line of least resistance, which is in the direction of the strike of the rocks.

There is another aspect of some interest. The height of the sandstones on the floor of the stream determines its general level of erosion, and hence the deepening of pot-holes in the shales does not directly lower the general surface of the stream-bed. Indirectly however, the erosion of the shales hastens that of the sandstones, and consequently the floor of the stream as a whole in the following manner. At low water, the sandstones project as bars above the water, which occupies the hollows in the shales. The sandstones thus become greater targets for the atmospheric agents of frost, rain and changes of temperature, than if they formed one nearly dead level. In the same way at high water and flood time, the sand and gravel carried along the stream bed, have a greater surface of sandstone to abrade than if the floor of the creek were level, notwithstanding that the hollows become partly filled with gravel, sand and other débris.

Summary.

The Nillumbik Peneplain, consisting of an elevated area—the Yarra Plateau—and a depressed area—the Croydon Senkungsfeld—is described and its age discussed.

The Croydon Senkungsfeld is shown to be a fault-block, bounded mainly by faults and their scarps. The faults traced are the Brushy Creek Fault, the Yarra Fault, and a probable fault named the Dandenong Fault. The latter has a length of nearly fifty miles, whilst the Brushy Creek Fault is traceable by its scarp for about eight miles, and the Yarra Fault similarly for about nine miles.

The uplift of the Nillumbik Peneplain was both slow and differential. It was so gradual that the Yarra was able to cut deep gorges—the Yering and Warrandyte Gorges—as fast as the land rose. The differential movement accounts for the Croydon Senkungsfeld, which is a relative and not an absolute depression.

The Yarra and Dandenong Creek Basins are divided by a line of elevated country—the Mitcham Axis—which is in part at least due to crustal movement.

The Yarra River is in a certain portion clearly antecedent to the present topography, and in its course through the Yering Gorge and part of the long Warrandyte Gorge is a revived stream.

The Yarra Flats and low adjacent country are primarily due to being part of the Croydon Senkungsfeld, through which vertical erosion almost ceased while the Yering and Warrandyte Gorges were being excavated, but lateral erosion was active.

The Yering Gorge is an isolated gorge of the Yarra, and is extremely valuable for the light it throws on the physiography of the whole district.

The Dandenong Creek and its principal tributaries are antecedent and revived streams.

The Bayswater and Scoresby Flats are within the Croydon Senkungsfeld, and belong to the Dandenong Creek Basin. Their origin is due to causes acting similarly to those which have caused the Yarra Flats.

A valley, forming part of the Croydon Senkungsfeld, stretches from the Yarra, through Croydon, Dandenong, the Carrum Swamp, and probably under the waters of Port Phillip Bay, as far as Dromana.

The composite nature and the growth of the Yarra are indicated.

The influence of the great masses of acid igneous rocks in the evolution of the topography is discussed, and a comparison made between the Upper Goulburn and Yarra Basins.

Gardiner's and Main Creeks are referred to, and the possibility of originally being distinct streams with their subsequent history is referred to.

Some monadnocks and view-points are described, and the possibility of peneplains older than the Nillumbik Peneplain is suggested.

The existence of rapids and small islands in the Warrandyte Gorge is noticed, and their relations stated.

An example of differential pot-hole erosion is given.

A list of the literature referred to is tabulated.

In conclusion, I desire to thank Prof. Skeats, Mr. F. Chapman, Dr. T. S. Hall and Mr. Griffith Taylor (now of the British Antarctic Expedition), for advice and helpful discussion on various points connected with this paper.

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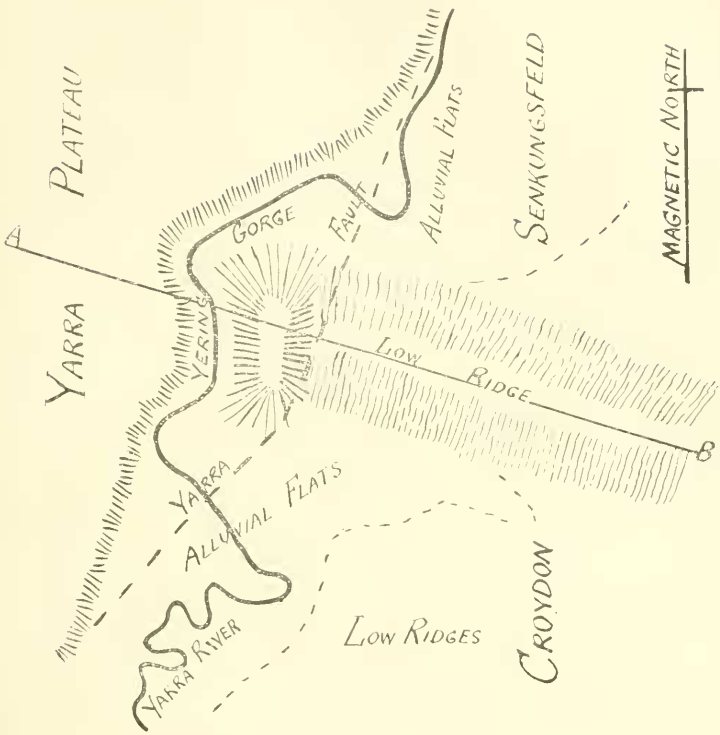

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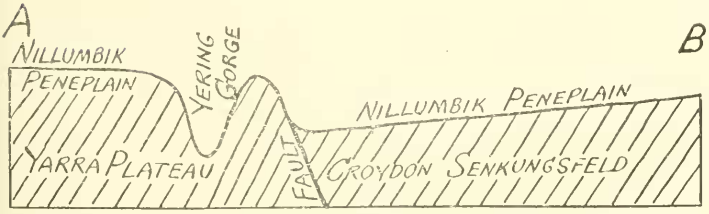

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